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Navigating the “Paradox of Openness” in Energy and Transport Innovation: Insights from Corporate Clean Technology Research and Development

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Abstract: Using an inductive case study approach drawn from original interview data, this article investigates the innovation approaches among a sample of international energy companies, or corporate firms. It first presents a conceptual framework synthesized from the business studies, entrepreneurship, evolutionary economics, innovation studies, management science, organization studies, political science, and sociology literature. This framework suggests that corporate approaches to clean technology innovation will cut across the four dimensions of organizational multiplicity and stakeholder involvement, information sharing, coordination and control, and market orientation. It then explores how eight firms—the Algal Carbon Conversion Flagship and Aurora Algae (biofuel), DONG and Statoil (carbon capture and storage), Tesla and Volkswagen (electric vehicles), and Siemens and Vestas (offshore wind turbines)—approach clean technology development with “open innovation” attributes mixed with “closed” attributes. Although the study finds striking similarities among the particular approaches embraced by each corporate actor, it also notes that approaches are technology and firm specific, and the potential for different permutations leads to an almost endless number of possible stylistic combinations. The innovation profiles depicted also reveal conflict and competition among various stakeholders, the implication being that corporate innovation in the energy sector remains a conflicted, disjointed, and messy process.

Keywords: open innovation; corporate research style; energy systems; transport

Navigating the “Paradox of Openness” in Corporate Clean Technology Innovation and Development

1. Introduction

This study investigates the integrated topics of energy systems, corporate sustainability, and organizational innovation from the standpoint of the corporate firm. As Fri and Savitz (2014: 183) have compellingly argued, “Managing climate change will require massive innovation in many of the planet’s major energy systems.” All too often, however, attempts to develop new technologies fail or encounter difficulties. Wilson et al. (2012: 781) go so far as to write that “directed innovation efforts are strikingly misaligned with the needs of an emissions-constrained world.” Gallagher et al. (2012) and Sovacool (2009; 2012; 2014) have echoed similar sentiments criticizing existing patterns of innovation among energy systems and transportation technologies.

Yet the literature on innovation studies has noted a perpetual tension facing industries and national programs attempting to develop new products and processes. There is a tradeoff between participatory openness and proprietary control. Laursen and Salter (2014) call this the “paradox of openness:” to innovate, firms need to draw from and collaborate with a large number of actors from outside their organization. At the same time, firms face countervailing pressures to focus on maximizing the returns from their innovative ideas. This gives rise to the paradox—the creation of innovations often requires openness, but the process of commercialization of innovations necessitates closure.

In this article, we explore how a sample of major international clean technology and energy companies navigate this paradox. Although we maintain that the paradox is not something to be resolved, it does offer a useful heuristic that explains and describes different approaches to innovation. Therefore, we ask: how do corporate firms approach innovation and development across a variety of energy and transport technologies? What aspects of their approach can be characterized as “open” or “closed?”

Using an inductive case study approach based on original data, we examine approaches to innovation within firms operating in the sectors of algal biofuel (Algal Carbon Conversion Flagship and Aurora Algae), carbon capture and storage (DONG and Statoil), electric vehicles (Tesla and Volkswagen), and offshore wind turbines (Siemens Wind Power and Vestas).

To do so, we draw from a synthetic conceptual framework incorporating insights from business studies, entrepreneurship, evolutionary economics, innovation studies, management science, organization studies, political science, and sociology. This framework suggests that corporate approaches to clean technology innovation will cut across the four dimensions of organizational multiplicity and stakeholder involvement, information sharing, coordination and control, and market orientation. Admittedly, these dimensions do overlap, and are not clearly orthogonal. Nonetheless, we find that although each company mixes different attributes of these dimensions, many commonalities exist—offering insights into not only the innovation and research process, but also the state of energy technology development and energy planning and policy. Moreover, multiple studies have suggested that the success of new energy alternatives such as offshore wind turbines or electric vehicles will depend entirely on research breakthroughs to be competitive (Awate et al. 2012; Heponstall et al. 2012; Kaldellis and Kapsali 2013). Thus, the future of the four technologies we explore—advanced biofuel, carbon storage, electric vehicles, and offshore wind turbines—hinges on the ability for corporate actors like those we explore to continue innovating their technical designs, production processes, and installation and construction techniques. Understanding how these actors innovate, the descriptive dynamics of their innovation approaches, is an elemental part of describing and then comprehending their patterns of research and development.

2. Research Methods and Concepts

To begin, this section of the study presents our conceptual framework and justifies our selection of technologies and corporate firms before explaining our methods of data collection, primarily semi-structured research interviews supplemented with a literature review.

2.1 Open and closed innovation

Our conceptual framework is rooted in the notion of open and closed innovation. Drawn from a synthesis of literature across multiple disciplines, we posit that corporate or firm approaches to innovation revolve around the two extremes shown in Table 1. To summarize, open approaches are epitomized by an inclusivity of actors and stakeholders, the encouragement of information sharing, the promotion of experimentation, flexibility, and adaptation, and a holism in terms of market orientation and the spanning of organizational boundaries. Closed approaches, by contrast, are punctuated by limited access and exclusivity, protections against information sharing, a centralization of activities with an intent focus on stated design principles or targets, and a narrow focus on technical development often confined within a single firm. The remainder of this subsection briefly justifies each of these dimensions.

Table 1: Typology of Open and Closed Approaches to Innovation

| <i>Dimension</i> | <i>Author(s)</i> | <i>Open approach</i> | <i>Closed approach</i> |
|---|---|---|---|
| Organizational multiplicity and stakeholder involvement | Nelson and Winter 1982; Hargadon and Sutton 1997; Cassiman, and Veugelers 2002; Laursen and Salter 2006; Andersson and Ostrom 2008; van deVrande et al. 2009; Ostrom 2010 | Inclusive of actors at various scales and of differing types, open to multiple stakeholders | Exclusive to a few select firms at limited scales, focused on limiting access |
| Information sharing | Allen 1983; Von Hippel 1987; Koschatzky 2001; Henkil 2006; | Cooperative and encouraging of information sharing | Competitive and encouraging of information hoarding |

| | | | |
|--------------------------|---|--|---|
| | Chesbrough 2006; Chesbrough and Appleyard 2007; Laursen 2012; Laursen and Salter 2014 | | and proprietary protection |
| Coordination and control | von Hippel 1986; Levitt and March 1988; Greenstein 1996; Verganti 2008; Enkel et al. 2009; Almirall and Casadesus-Masanell 2010; Smith and Shaw 2013 | Decentralized and conducive to diversity and experimentation, flexibility, and adaptation | Centralized and predicted on consolidation and rigidity in design processes, methods, and targets |
| Market orientation | Jaffee and Stavins 1994; Guston 1999; Antoncic and Hisrich 2001; Rosenkopf and Nerkar 2001; Geels 2002; Ekboir 2003; Hounshell 2004; Godin 2006; Geels and Schot 2007 | Holistic in valuing technical and social considerations and spanning organizational boundaries | Narrow in focusing predominantly on technical development confined to within a firm |

Source: Authors

The premise of the dimension of *organizational multiplicity and stakeholder involvement* is relatively simple: the process of innovation involves transaction costs. It involves a resource-intensive search to find new combinations of knowledge or technology to exploit. This, however, demands that firms work with and draw data from many actors outside their organization (Hargadon and Sutton 1997; Laursen 2012; Laursen and Salter 2014). In a similar way, political scientists discuss the effectiveness of polycentric or nested collaborations between institutions that can better respond to collective action problems or manage public goods because they involve a heterogeneity of actors cutting across scales and sectors (Andersson and Ostrom 2008; Ostrom 2010). Business studies scholars have also noted that small and medium enterprises may rely especially on collaborative innovation as a way to bundle resources together to help counter larger firms dominating a market (van deVrande et al. 2009). These

themes all point in favor of openness, inclusion, and cooperation. However, other literature supposes that organizational involvement needs counterbalanced with the demands of protection. That is, firms need to protect and control knowledge and innovation, or else risk loss of skills or worse theft of intellectual property (von Hippel 1987; Cassiman and Veugelers, 2002). Greenstein (1996) has noted that openness in the aerospace industry increases costs because it requires the cooperation of multiple suppliers in a complementary configuration. Almirall and Casadesus-Masanell (2010) also concluded that openness has drawbacks, which they even quantify as a divergence cost, suggesting that when a product or system is opened to outside actors, control over design and development of the technology is weakened. These themes all point in the direction of closure.

The *information sharing* dimension is derived from a debate in the innovation, business, and organization studies literatures about how firms position themselves and either share or hoard knowledge (Laursen and Salter 2006). Evolutionary economists sometimes identify the role of information searching in facilitating organizations to find sources of variety and novelty that allow them to create new combinations of knowledge that lead to technological breakthroughs (Nelson and Winter, 1982). Koschatzky (2001, p. 6) notes “firms which do not cooperate and which do not exchange knowledge reduce their knowledge base on a long-term basis and lose the ability to enter into exchange relations with other firms and organizations.” Chesbrough (2006) argues that sharing ideas, especially unused or underutilized ones, contributes to a “decongestion” of the internal innovation process. Chesbrough and Appleyard (2007) add that many successful new companies, especially in information systems, software, and social media, rely on external, volunteer contributors where the sharing of knowledge (freely, often) is a critical element of the innovation process. These themes point in the direction of openness. However, others argue that firms must not share knowledge unequivocally. Henkel (2006) describes a process of “selective revealing” where firms in the computer software industry sometimes reveal information and

knowledge without being obliged to do so, but then they only reveal about half of the code developed. Those writing in support of strong intellectual property protections also frequently invoke the claim that stringent copyrights—essentially closed access to information—are needed to reward invention and stimulate further innovation (Kraemer 2006: 88; Moore 2006; Magas 2004). This theme points in the direction of closed innovation.

The dimension of *coordination and control* finds its roots in discussions about decentralization and diversity versus centralization and consolidation in the innovation process. Smith and Shah (2013) for instance argue that medical device firms that incorporate feedback and knowledge from “user innovators” are more effective at developing patents and “highly innovative products” than firms that do not. Von Hippel (1986) similarly notes that “lead users” can be a key source of input into the innovation process. Those subscribing to “design-driven innovation” have also made the case that firms that organize technological development around fluid visions, missions or challenges, rather than more rigid targets and principles, can create a symbiotic dialogue that both develops a better product and stimulates market demand (Verganti 2008). Levitt and March (1988) refer to this as “target oriented” organizational learning; Allen (1983) terms this “collective invention.” These themes all point to openness. However, Enkel et al. (2009) note that companies investing in open innovation activities face risks and barriers that hinder them from profiting from their initiatives—particularly acute risks involving loss of knowledge, higher coordination costs, loss of control, and greater complexity. These are in addition to internal factors such as difficulty in finding the right users or partners, an imbalance between partners, and insufficient time and resources to explore partnerships. These themes all point in favor of closure.

The dimension of *market orientation* relates to both entrepreneurship and intrapreneurship as well as whether innovation approaches orientate themselves towards purely technical or sociotechnical development. Rosenkopf and Nerkar (2001) find that organizations that position themselves to cross

organizational and technological boundaries have higher positive effects on technological evolution than those that stay within established boundaries. Jaffee and Stavins (1994), Geels (2002), and Geels and Schot (2007) also all note that more successful diffusion of niche innovations tends to occur when an alignment of technical configurations is reached alongside social, political, and behavioral aspects. These themes suggest a more open and flexible market orientation. Antoncic and Hisrich (2001), by contrast, suggest that many successful firms look within the organization, rather than outside or beyond it, in a process they term intrapreneurship—innovation comes from within, rather than without. Other research has demonstrated the attractiveness of a “linear” model of innovation and development that suggests that the process focuses exclusively on technology, beginning with basic research before moving to applied research (Godin 2006; Ekboir 2003; Hounshell 2004; Gustin 1999). Market development and consumer acceptance must come later, after the technology’s utility has been demonstrated. The model remains attractive among scientists, engineers, and public policymakers because it suggests that technological diffusion is more or less automatic and unmanaged, and it also stipulates easily defined roles. Politicians are to set research agendas and dictate preferences, scientists and engineers are to meet them. The model implies that little interaction is needed with other actors beyond scientists and engineers. An emphasis is placed on linearity and closure.

In this study, we have chosen eight corporate actors utilizing a mix of these open and closed dimensions. We also realize that most approaches fall along a continuum of open or closed rather than sitting at the extreme, and have thus analyzed on a spectrum rather than as an absolute. Furthermore, we admit that many dimensions both overlap and interrelate, implying that they can affect each other in complex and mutually constitutive ways.

2.2 Technology and company project selection

As is obvious by now, this study looks at clean technology development from the scale or unit of analysis of the corporate firm. This is because worldwide business and industries account for about 58% of energy use in a multitude of settings (Ruhns and Wyatt 2011; U.S. Energy Information Administration 2007), and businesses are also a major gatekeeper for the emission of greenhouse gases (Heede 2014). For our selection of energy technologies and cases, we wanted representative coverage of both electricity and transport—the two largest sources of energy consumption—as well as a comparison of relatively mature systems compared with new, cutting-edge ones in addition to a variety of geographic contexts. We selected algal fuel (transport, non-commercialized), carbon capture and storage (electricity, non-commercialized), offshore wind turbines (electricity, commercialized), and electric vehicles (transport, commercialized). As Table 2 indicates, this creates a fairly representative matrix of different firm types and energy systems. This section of the paper briefly justifies each of the particular technologies and corporate actors investigated.

Table 2: Typology of Clean Technology Innovation and Development Cases

| | <i>Technology type</i> | | <i>Firm type</i> | | <i>Location</i> |
|----------------------------------|----------------------------------|----------------------------------|------------------|-------------|-----------------|
| | Sector(s) | Level of technological readiness | Size | Incumbency | |
| Algal Carbon Conversion Flagship | Biofuel, transport, and mobility | Non-commercialized | Small | New entrant | North America |
| Aurora Algae | Biofuel, transport, and mobility | Non-commercialized | Small | New entrant | Asia-Pacific |

| | | | | | |
|--------------------|---|--------------------|------------------------|-------------|---------------|
| Statoil | Carbon capture and storage, greenhouse gas removal, carbon dioxide management | Non-commercialized | Large | Established | Europe |
| DONG Energy | Carbon capture and storage, greenhouse gas removal, carbon dioxide management | Non-commercialized | Large | Established | Europe |
| Tesla | Automotive manufacturing, electric mobility | Commercialized | Small | New entrant | North America |
| Volkswagen | Automotive manufacturing, electric mobility | Commercialized | Large | Established | Europe |
| Vestas | Wind turbine engineering and design | Commercialized | Small | Established | Europe |
| Siemens Wind Power | Wind turbine engineering and design | Commercialized | Large (parent company) | New entrant | Europe |

Source: Authors

Algal fuels, produced in raceway ponds or photo-bioreactors, can be grown on otherwise non-productive or non-arable land, including deserts (Slade and Bauen 2013). These types of biofuel operations can recycle carbon dioxide and other waste streams, and can thrive using saline water, brackish water, and wastewater (Bazilian et al. 2013). We selected two corporate actors or research programs producing algal biofuel for analysis in our study, based primarily on their different corporate structure and innovation approach: the Algal Carbon Conversion Flagship and Aurora Algae. The Algal Carbon Conversion Flagship is an industry alliance backed by the Canadian National Research Council aimed at facilitating the commercial development of anaerobic digestion of microalgae biomass (Bjornsson et al. 2012; Bjornsson et al. 2013). They utilize a process with microalgae to first separate lipids and dry mass before processing the lipids in a bio-refinery. The Flagship features more than a

dozen specific companies ranging from large final emitters to smaller enterprises dedicating more niche solutions from algal biofuel. One major component of the Flagship has been a \$19 million test facility in Alberta where Canadian Natural and Pond Biofuels are conducting feasibility studies on the viability of large-scale algae cultivation. Other plans include a demonstrate algae bio-refinery to be built near Bonnyville at Canadian Natural's Primrose South oil sands site. Aurora Algae Inc. has a different approach to algae biofuel, as their focus has been primarily on the lipids and its potential as an oil alternative in the form of diesel and petroleum. This is done by extracting the lipids from the algae mass for oil production and the leftover dry-mass is used to produce feed and protein for animals and humans. Aurora started as a company in California focusing on making biofuels from algae only using CO₂ as a feedstock, rather than a volatile agricultural commodity like sugar or corn. It, also, is a privately held company that is funded by various investors, banks, and public grants such as one from the state of Western Australia. Aurora Algae claims that their algae crops is capable of producing a wide range of alternatives for existing products and have the potential to supply numerous markets such as pharmaceuticals, supplements, nutrition, and biofuels. Strains can thrive in open pond systems that operate in seawater instead of fresh water, to conserve natural resources. Also, instead of a traditional centrifugal approach Aurora Algae has pioneered a unique, energy-efficient harvesting method that is commonly used in the wastewater treatment industry.

Our second chosen technology is CCS, techniques which gather carbon dioxide (either before fuel is burnt or at the point of combustion) to and then store it underground, thus preventing it from being released into the atmosphere. We selected two corporate research programs for CCS, both considered pioneers, and both heavily investing in pilot projects: DONG Energy and Statoil. DONG Energy is one of the leading energy groups in Northern Europe with about 7,000 employees headquartered in Denmark. They specialize in producing oil and natural gas, generating electricity and heat from offshore wind farms

and power stations, and supplying energy to residential and business customers. DONG started experimenting with CCS technology in 2006 with their Esbjergværket Project. The \$45 million project developed a post-combustion capturing device, which is primarily used for testing of new absorbents in order to decrease the energy consumption of extracting CO₂ out of the flue gas. The CCS module was applied to the existing power and heating plant with the capacity of 371 MW located in Esbjerg in the southwest of Denmark. Statoil is an international energy company with operations in 36 countries and it is headquartered in Stavanger, Norway with approximately 23,000 employees. Statoil has a long history in the development of CCS technology. In 1996 they opened the world first commercial CCS project at their Sleipner West gas rig in the North Sea. Here, we have chosen to examine a newer CCS project, Technology Center Mongstad, which started in 2011. The \$62 million TCM had two tracks testing post-combustion carbon-capture techniques. One was using ammonia to trap CO₂, the other using an amine chemical. Both removed 85-95 percent of the CO₂ contained in the flue gas after combustion of the fossil fuel. TCM works as a test facility with the purpose of commercializing the CCS technology.

Our third chosen technology was electric vehicles (EVs). EVs can greatly reduce or eliminate tailpipe pollution and curtail greenhouse gas emissions compared to internal combustion engine vehicles; moreover, consumers and drivers often profit from the use of EVs because electricity is cheaper than gasoline for equivalent distances traveled (International Energy Agency 2013). We selected two corporate research programs, one at a major automotive manufacturer, the other at a new entrant: Tesla Motors (Tesla) and Volkswagen Group (VW). Tesla was selected because they are a young company, founded in 2003, with a strategy to deliver EVs to the mass market. This entrepreneurial approach has forced them to rethink industry standards regarding ways of developing and designing vehicles with a pure electric focus. Tesla's primary mission is to develop and commercialize EVs first in the premium sports car market before moving into more mainstream vehicles such as sedans and non-luxury models.

This is clearly evident through their EV development roadmap, where they first launched their premium-priced-niche model Tesla Roadster, when production costs were still very high. Subsequently, the Model S was introduced, a high-end family sedan, with prices starting at approximately half those of the Roadster. Future models are expected to increase in volume and decrease to half the price of Model S. VW, on the other hand, is (as of 2015) the world's largest automotive company in terms of sales in 2015. Their size makes them world leader within the automotive industry giving them some advantages of scale and economics that combined with almost a century of experience from petroleum fuelled vehicles—VW

has been manufacturing automobiles since 1937. Their development of EVs is much more recent, beginning formally with the launch of a prototype in 2009 at the 63rd Frankfurt Motor show in Germany, followed by hybrid electric vehicles in 2013 and full battery EVs in 2014.

Our final chosen technology was offshore wind turbines. Offshore wind energy brings considerable advantages compared to its onshore partner. Wind resources are stronger, more predictable, and less turbulent at sea; most offshore sites are located far from communities, limiting concerns about visual impact, noise, and social opposition; and lower wind-shear enables the use of shorter towers and fewer physical restrictions (such as passage under bridges) exist to impede transport and construction from harbor to site (Sovacool and Enevoldsen 2015). We selected two corporate research programs, one long-established (Vestas) and one newer (Siemens Wind Power), yet both the two market leaders for offshore wind farms. In terms of market share, in 2014, these two companies dominated the global market—Siemens represented 55 percent of accumulated offshore wind farm installations followed by Vestas with 27 percent. Both companies offered more than ten different offshore turbine models, had more than 11,000 employees, €5 billion or more in revenues, and similar installation costs for developers. Vestas is known for licensing the rights to the three-bladed turbine design that has come to dominate the

market, for introducing the first pitch-regulated wind turbine in 1985, the first light weight blades in 1990, the first direct drive generator in 1994, the first low-wind-speed turbine in 1999, and for manufacturing the first major offshore wind farm, Horns Rev in the North Sea, in 2001. Though a newer entrant than Vestas, Siemens Wind Power has led the industry in a number of innovations since entering the market in 2004 by purchasing Bonus A/S. They launched the first detailed software monitoring system. They piloted the B75 rotor blade, which is constructed in one piece without glued joints and adhesives, reducing weight. They perfected direct drive technology, which utilizes a gearless drive train to increase reliability and availability. They were also the first to deploy their own fleet of tailor-made ships for installation of offshore wind turbines, reducing installation times.

2.3 Data collection

Given the relative paucity of information concerning innovation approaches across these four technologies and eight corporate actors and programs, we relied on semi-structured research interviews at our primary source of data. We conducted a total of 33 interviews in 6 countries at 20 institutions—either actors directly involved in projects, or those with knowledge of them—over the course of 2014 and 2015, with Table 3 providing more details about specific dates and firms interviewed. In each case, we spoke with respondents at institutions beyond merely those being investigated to put things in broader context. Each interview lasted between 30 and 90 minutes, and we followed the same script, asking always questions about firm collaboration, approaches to research and innovation, and challenges. All interviews were transcribed and coded, though in each case, to encourage candid and complete responses and to protect the confidentiality of respondents, we present data from such interviews as anonymous.

Table 3: Summary of Semi-Structured Research Interviews

| Technology | Case Study Project | Institution | Country | No. Interviews |
|---------------|----------------------------------|----------------------------------|---------|----------------|
| Algal biofuel | Algal Carbon Conversion Flagship | Algal Carbon Conversion Flagship | Canada | 3 |

| | | | | |
|----------------------------|----------------------------------|--|---------------|-----------|
| Algal biofuel | Algal Carbon Conversion Flagship | Symbiotic Environment Technology Incorporated | Canada | 2 |
| Algal biofuel | Aurora Algae | Aurora Algae | United States | 2 |
| Algal biofuel | Aurora Algae | Department of Microbiology, University of Florence | Italy | 1 |
| Carbon capture and storage | DONG | DONG | Denmark | 3 |
| Carbon capture and storage | DONG | Geological Survey of Denmark and Greenland | Denmark | 1 |
| Carbon capture and storage | DONG | Center for Energy Resources and Engineering, DTU | Denmark | 1 |
| Carbon capture and storage | Statoil | Statoil | Norway | 2 |
| Carbon capture and storage | Statoil | Department of Chemical Engineering, DTU | Denmark | 1 |
| Carbon capture and storage | Statoil | MIT Energy Initiative | United States | 1 |
| Carbon capture and storage | Statoil | U.S. Department of Energy, Office of Fossil Energy, Division of CCS Research | United States | 1 |
| Carbon capture and storage | Statoil | Lindas Municipality | Norway | 1 |
| Electric vehicles | Volkswagen Group | Volkswagen Group | Germany | 3 |
| Electric vehicles | Volkswagen Group | Free University of Berlin | Germany | 1 |
| Electric vehicles | Tesla | Tesla | United States | 2 |
| Electric vehicles | Tesla | Insero e-mobility | Denmark | 1 |
| Offshore wind turbines | Siemens Wind Power | Siemens Wind Power | Denmark | 3 |
| Offshore wind turbines | Siemens Wind Power | Department of Wind Energy, DTU | Denmark | 1 |
| Offshore wind turbines | Vestas | Vestas | Denmark | 2 |
| Offshore wind turbines | Vestas | NOAH (non-governmental organization – primarily supporting solar and wind power) | Denmark | 1 |
| Total | 8 | 20 | 6 | 33 |

Source: Authors

Admittedly, the use of stated preference methods such as interviews does have some notable strengths and weaknesses. As a positive, interviews enable interactivity because they encourage participants to talk openly, and allow the conversation to attain suitable momentum that enables more complex and complete exploration of topics (George and Bennett, 2004). Moreover, the visual element of the interviews enabled us to look for nonverbal cues to decide whether a respondent understood a question (King et al., 1994). As a negative, the qualitative aspect of interview responses makes them

difficult to code and answers understandably vary for each participant. Inaccuracies could also arise due to poor recall and memory of the interviewee (Kroes and Sheldon, 1988). We have attempted to minimize these negatives and maximize the positives by validating the interviewing findings with a secondary method, that of a literature review. To supplement our primary data, and compensate for a relatively small sample size of interviews, we sought to conduct a comprehensive literature review inclusive of company documents, memorandums, press releases, brochures, and annual reports from both all eight of our companies published in the past five years.

3. Results and Discussion

This section of the paper presents our results, organized by each of the four technology areas (algal biofuel, CCS, EVs, and offshore wind). Each section starts with a paragraph explaining each project before comparing and contrasting the specific style according to the four dimensions of organizational multiplicity and stakeholder involvement, information sharing, coordination and control, and market orientation.

3.1 Algal biofuel

As Table 4 indicates, we argue that the Algal Carbon Conversion Flagship adopts a relatively open research style whereas Aurora Algae uses a relatively closed approach.

Table 4: Eight Caricaturized Corporate Approaches to Clean Technology Innovation

| | Completely open | | | | Moderately open | | | | Neither | | | | Moderately closed | | | | Completely closed | | | | |
|-------------------------------------|-----------------|--|--|--|-----------------|--|--|--|---------|--|--|--|-------------------|--|--|--|-------------------|--|--|--|--|
| Inclusive and participatory | | | | | | | | | | | | | | | | | | | | | Exclusive and proprietary |
| Cooperative and information sharing | | | | | | | | | | | | | | | | | | | | | Competitive and information protecting |

as to assess the potential bioenergy and bioremediation of a microalgae strain was also publicly published (McGinn et al. 2012). This indicates a desire to share information with researchers beyond the Flagship. As one respondent noted, “the ACCF also shares all their own and non-sensitive research data and make it publicly available.” It thus works with stakeholders of varying capacity and interests and publish all the research done on algae strains, lipid content to extractions technologies. Though some collaborations remain private and confidentiality, most are open to participation. Conversely, Aurora exhibits somewhat extreme protection of information and seems to view other firms as competitors rather than partners. Knowledge is generally kept within the company and not disclosed to other researchers or the public. According to one respondent, “Aurora is focused on limiting access to the company and their research results and knowledge.” Another stated that “they seem extremely sensitive about intellectual property and also require non-disclosure agreements before they will disseminate research results, even to members of universities.”

In terms of *coordination and control*, the Flagship is mostly open. Some of its work is done in a decentralized way at different firms and laboratories, yet other members of the Flagship prefer to keep research in house—under control that is more central. Put another way, their decentralization does not extend beyond select government, industrial, and academic partners. In addition, being a research and development platform, the Flagship enjoys a degree of flexibility. Researchers have chosen to look at various strains of algae and also chosen to experiment with the measurement of the potential bioenergy of these strains, through looking into direct combustion, anaerobic digestion and lipid extraction. They also seem to adapt targets and future strategies as they progressively gain a better understanding of algae performance. This flexibility has its bounds, though, since it never extends beyond the four stated areas of identifying strains, using photo-bioreactors, improving efficiency, and exploring other value streams. Aurora Algae differs by being almost completely centralized, with all partnerships and even information

under the control of its senior management. Aurora seems more focused on returns on investment, thus they do experiment but, as one respondent noted, “keep this limited in scale and scope to what is most commercially advantageous.”

Interestingly, when it comes to *market orientation*, we see the actors occupying the same approach of being relatively closed. While the Flagship is very concerned for the environmental impact of their studies, their research does mostly concern technological evaluation and development. Looking at their holistic aspects it is in regards to environmental sciences such as local strains of algae and low risk of invasion, closed PBR reactors for ease of utilization and deployment, environmental friendly ways of extracting the lipids, as well as the overall study of the pathways in which bioenergy will have importance in Canada. This means that are deemed more holistic as far as environmental concerns are considered yet still have a rather narrow perspective and only developing technologies so as to establish a commercialization scale production of microalgae in congruence with several end-product opportunities. Aurora is concerned with market penetration of their technologies as well, but admits they take a narrower view and focus mostly on “pre-revenue” activities and technology development. They hope that if they can work these out, the rest—adoption and commercialization—can follow.

3.2 Carbon capture and storage (CCS)

Table 3, above, also summarizes our results for the two CCS corporate approaches. As it indicates, DONG Energy pursues mostly a closed approach whereas Statoil relies on mostly an open approach, though the specific dimensions vary.

In terms of *organizational multiplicity and stakeholder involvement*, DONG Energy’s Esbjergvaerket is inherently open. As it was an EU-funded project receiving about € 12.5 million in public money, a certain degree of openness was imposed upon the project. This placed the Esbjergvaerket project as a rather inclusive one. Furthermore it seemed that the inclusive nature of the

project affected the actual test facility, as the solvents used were based on prior research conducted by the participating educational instances. Yet although the Esbjergvaerket project had elements of being inclusive, and thus would seem to be participatory, our interviews revealed that the project was more proprietary in its focus, and sought to limit the access of actors outside of the initial participant-list—so it wasn't entirely open. Similarly, due to its stated function as test facility, the TCM was also open, involving numerous industrial participants and also releasing results to the broader public. The TCM facility was also available for whoever wanted to do tests within the area of CCS technology. Each project had its own agreement of conditions but dozens and dozens were completed during its tenure.

Similarly, in terms of *information sharing*, the TCM was more open and DONG Energy more closed. To be fair, both projects were somewhat ambiguous when it comes to the sharing of information. The Esbjergvaerket project showed to be willing at sharing information internally with actors participating in the program, however limiting the access and information going to companies outside of the program, and only providing them with need-to-know information when asked to do a task. The TCM project was in general more willing at sharing information, which might be based on the fact that it is government funded and seeks to develop and promote the CCS technology in general, rather than with the aim of commercializing it into a specific product. Elements of competitive information hoarding is however found in relation to some of the sub-projects run at the test facility, as companies involved is given the ability to secure any IPR in a certain timeframe, giving the ability to gain an competitive advantage, before any results is publicly available.

In terms of *coordination and control*, DONG Energy gravitates towards a closed style and TCM an open one. DONG Energy exerted tighter control over its Esbjergvaerket project, since it was obligated to maintain and run the power plant while conducting testing's, thus limiting the degree of experimentation allowed. Moreover, DONG Energy was almost entirely rigid, setting a series of

predetermined goals and timelines that they did not deviate from, even in the face of challenges. The overall idea of Esbjergvaerket was furthermore to test a specific test setup of solvents on a preexisting power plant, thus limiting the amount of flexibility and autonomy. TCM and their strategy of promoting and developing the technology in general makes it more decentralized, as the facility itself is open for multiple actors and experiments. The sub-projects run at the facility are moreover controlled by the sub-actor self, thus bringing diversity and decentralized aspects to the TCM project as a whole. The TCM project is also much more flexible in its setup, as sub-projects, as previously mentioned, are autonomously controlled by the sub-actor in charge of the project. It was intended to promote flexibility without any specific and preset goals other than to promote and develop the overall technology of CCS.

Lastly, in terms of *market orientation*, Esbjergvaerket, with the goal of commercializing the CCS technology, predominantly focused on the development of specific CCS-technical solutions, which could be characterized as having a narrow perspective. By including actors and by extending the network of TCM wider than to just technical collaborators, TCM, according to one respondent, “arguably has an integrated holistic approach to CCS research.” Our participants suggested that TCM showed that they include actors to “help develop the business possibilities in CCS,” and “actively contribute to the promotion of CCS acceptance in general.”

3.3 Electric vehicles (EVs)

In our EV cases, we see a more complex blending of styles, with Volkswagen being seemingly closed though more open in terms of flexibility and Tesla being more open yet closed when it comes to vision and rigidity. Table 3, above, illustrates our results for these two companies.

In terms of *organizational multiplicity and stakeholder involvement*, Tesla’s approach is highly inclusive of actors of differing types and scales. They collaborate highly with industrial partners to develop and manufacture their cores technologies (battery performance). Their customer innovation

project with Stanford School of Business, and interaction with the US Government – Department of Energy, proves furthermore that their inclusive approach reaches out to different types of actors. As a new entrant to the automotive industry, Tesla's approach attempts to achieve exploitable synergies that arise as the industry evolves. Therefore, they seek to "inspire other automotive companies and suppliers to get involved and tap into the growing consumer demand for sportive performance combined with socially responsible mobility." In order to achieve this vision, Tesla have taken what one respondent called "an explicitly collaborative approach to their R&D and also the control of their intellectual property." As one of the Board Members we interviewed stated, "Tesla was created to accelerate the advent of sustainable transport. If we clear a path to the creation of compelling EVs, but then lay intellectual property landmines behind us to inhibit others, we are acting in a manner contrary to that goal. Tesla will not initiate patent lawsuits against anyone who, in good faith, wants to use our technology." They have, for instance, undertaken collaborative research projects with Panasonic on battery cells, Dana Holding Corporation on heat exchange technology, Toyota on plug-in devices, and Daimler on chargers. VW's research style is more exclusive due to their size and willingness to purchase and own knowledge. One of our interviewees stated that "a great deal of money is spent at VW developing in-house knowledge upon the electric vehicle area as well as hired 400 top experts and trained 70.000 employees to be ready for this change in drivetrain focus." They are not completely closed, though. VW has conducted joint research projects with Toshiba on batteries and electric drive trains, Budapest University on modular production and automation, and Lawrence Berkeley National Laboratory in the United States on energy storage and charging infrastructure.

In terms of *information sharing*, the results of Tesla's research are widely available for stakeholders making their research style highly participatory. They encourage other automotive manufacturers to use their intellectual property to develop their own EVs for the good of the future EV

industry. Videos-strip-downs of the Model S, which explain how the car is designed and manufactured are readily available and Tesla furthermore invite stakeholders to come to their factories to understand how their cars are manufactured. On the other end of the spectrum, the massive investment in in-house know-how and high amount of patent applications makes us situate VW as proprietary. Very little material has been found revealing information of their production or research. This defensive approach might be related to their size as market leader on automobiles.

In terms of *coordination and control*, Tesla's research style is dominantly decentralized in the sense that they allow their R&D to take place both inside and outside their boundaries. Their strategic approach to alliances, accepting that they need knowledge and experience from other actors, is highly evident through the alliances mentioned above. It is also significant to note that external actors develop some of their core technologies. However, Tesla's research style is highly rigid in the sense that Elon Musk has a clear goal for what technologies and EVs he wants Tesla to make. They will only do EVs and nothing else. VW, by contrast, doesn't seem to have many partners at a Group-level, though some decentralization within the group spread across the 12 brands exists. However the overall trend seems towards centralization and doing things in-house, due to the size, experience, and bargaining power of VW. Our interviewees also considered VW flexible since "they tend to cover all customer segments, drivetrain types and owns brands for every market." One of our interviewees estimated that VW spent some \$58 billion in research over the past decade on developing EVs alongside advanced drive and diesel engines and flex fuel vehicles and hybrids—a very flexible approach. Generally their research and products are broadly focused towards mass-satisfaction. Moreover, VW relies on a "modular platform" which enables them to produce cars with different drivetrains bumper-to-bumper, at the factories, with nominal components. This platform makes it easy to somewhat customize the drivetrain for local, national and regional environmental regulations.

In terms of *market orientation*, Tesla's research style is highly holistic. They consider all aspects of mobility when developing their EVs. The technology is obviously in focus, but so too is consumer acceptance, customers' buying experience, after sales and service. Tesla invests resources to understand driving trends and patterns helps them design and build their charging infrastructure to meet these needs. VW is almost as open, though they tend to direct more of their research efforts on technology rather than driving behaviour. Their strategy has emphasized low-emissions vehicles as well as intelligent networks, driverless cars, and infrastructure for charging.

3.4 Offshore wind turbines

In our offshore wind cases, we found—unexpectedly—two actors using the same style, as Table 3 above also caricaturizes.

In terms of *organizational multiplicity and stakeholder involvement*, both Vestas and Siemens are inclusive and open, and participatory. Vestas has exhibited an amenity towards collaborating with multiple actors, even, at times, potential competitors. A project in the Netherlands, the Egmond aan Zee Offshore Wind Farm, featured a joint venture in 2001 with Ballast Nedam (a Dutch construction and engineering company) known as Bouwcombinatie Egmond. That partnership saw Vestas cooperating closely with three other companies and three universities. In 2008, the company initiated a “Global University Program” where doctoral students and professors could receive small grants or fellowships; that same year, in India, they formed partnerships with the Center for Wind Energy Technology in Chennai and the Indian Institute of Technology in Madras. More recently, in 2013, Vestas committed to a joint venture with Mitsubishi Heavy Industries where the development of the V164-8.0 MW turbine, the V112 offshore order backlog, and existing offshore service contracts went to Mitsubishi, along with 300 of their employees. Similar to Vestas, Siemens has shown a proclivity to partnering with a diverse group of corporate and even non-profit entities. In 2009, the company prototyped the world's first ever

floating platform, called Hywind, developed jointly with the Norwegian oil and gas company Statoil and built near Karmøy. Siemens has collaborated repeatedly with DONG Energy on the design, installation, and operation of large offshore wind farms, especially those using 6 MW SWT-6.0-154 turbines. In 2011, Siemens and Shanghai Electric agreed on a strategic wind power alliance for the Chinese wind market.

In terms of *information sharing*, both actors are relatively closed. Vestas reorganized their operations and established an internal “Research and Development Business Unit” in 2005 to create a network of competencies within the company so that they could protect information. Rather than outsource innovation even in their operations worldwide, Vestas instead created their own research network, as part of this Unit, consisting of in-house facilities in the Isle of Wight (United Kingdom), Singapore, Chennai (India), Houston (Texas), Beijing (China), Boston (Massachusetts), and Boulder (Colorado). Moreover, although Vestas does engage in partnerships and joint ventures, they are also careful about restricting the flow of information, especially intellectual property or confidential trade secrets. Vestas, for instance, has been known to withhold knowledge and information from suppliers and sub-contractors on the grounds that they could jeopardize trade secrets. In other instances, Vestas has actively enforced the protection of their intellectual property rights through lawsuits, suing Beaird Industries for infringing on patents over tower designs. Siemens, too, is careful about restricting the flow of information, especially intellectual property. Patents, and their protection, are seen as an essential part of the Siemens process. As Siemens states explicitly on its website, “the protection, utilization, and expansion of the company’s intellectual property is vital to its success.”

In terms of *coordination and control*, management at both companies is also relatively centralized. Even when using their own people increases the expense of research, Vestas prioritizes keeping things internal. When they set up new facilities abroad, they usually rely on a strategy of sending their own “flying squads”—staff from existing operations—to initiate operations rather than hire local

people. When Vestas formed a new subsidiary in Italy, they used existing employees from Germany and the Netherlands rather than outsource. Analogously, after the acquisition of Bonus, Siemens started to construct all of the main components themselves at facilities in Denmark, China, and North America. These activities all make SWP similar to Vestas in focusing organizationally on internal research. Siemens offers training courses to all employees and has established an internal system to keep tight track of ideas, and to ensure that intellectual property derived from them stays within the company.

That said, both companies also prioritize a fair amount of experimentation and flexibility. When initially deciding which materials would be optimal for offshore turbine blades, engineers experimented with balsa, birch, and other woods along with strong plastics such as polyethylene terephthalate and various carbon composites. When deciding how to best design blades for transport and installation, the company experimented with making smaller blades in two or more pieces and reassembling them onsite, an idea they abandoned due to increase fatigue and shorter lifetimes. Siemens has also prided itself on autonomy innovation and flexibility prompted from the “bottom-up” or through groups composed of mid-level employees and managers. Though external information dissemination is restricted, internal information sharing is encouraged and even incentivized. Siemens AG has invested at least \$1 billion in its own “knowledge management” systems to promote the sharing of information, and for much of the past decade it even ran a peer-to-peer competitions, with rewards, to give employees “shares for their contributions to the company.” These shares, earned by participation or mentoring, could even be accumulated and turned into tangible prizes such as free mobile phones, laptops, or international vacations. Employees behind any particularly innovative ideas are rewarded if they end up benefitting the company.

Finally, in terms of *market orientation*, both Vestas and Siemens are open in this regard. Both try to meet diverse market segments with different technological configurations and options. The 3 MW

offshore platform from Vestas offers 13 different configurations across five turbines based on local wind speeds and turbulence. Some have larger rotors and extremely robust designs for tough site conditions and severe wind speeds; others are equipped with full-scale converters to meet local grid requirements in Ireland or the United Kingdom. Still others are suited for cold climates and feature a de-icing system, or are intended for low wind regimes and feature structural shell blades and a larger but more slowly turning rotors. Diversity in configurations is matched by a diversity of options available to purchasers. For sites near airports or military bases, they offer aviation lights, aviation markings on the blades, and “stealth technology” that minimizes interference with radar. For sites near shipping lanes, turbines can be equipped with an Obstacle Collision Avoidance System. Siemens also has products matched to optimal wind resources and configurations. The company has developed turbines with small or large rotor diameters for usage at low-wind onshore sites to high-wind offshore sites. Furthermore, smaller wind turbines with a lower rotor diameter are considered suitable for countries with tip height restrictions, and different tower heights are configured for each type of wind turbine. Siemens also offers turbines for harsh and cold conditions with special rotors and blades made with fiberglass-reinforced epoxy resin, eliminating glue joints that can lead to cracking, ice formation, and lightning damage. For less reliable grids in emerging markets such as Africa and Asia, Siemens offers customers a “NetCoverter” system that can fully convert all power generated to the grid, better regulate voltage, frequency, and output, and decouple turbines during unexpected outages.

4. Conclusion and Policy Implications

Despite a selection of case studies spanning four different energy systems and eight corporate firms, locations, innovation pathways, and levels of readiness, there were striking similarities and differences among the particular approaches embraced by each corporate actor. Vestas and Siemens, interestingly, adhered to the same approach, despite both firms having different attributes related to

geographic location, size, and tenure in the industry. Vestas is essentially a large Danish company who has led the world in the manufacturing of onshore and offshore turbines for decades. Siemens Wind Power is a smaller German spinoff who is a new entrant that has only recently come to dominate the niche offshore wind market. However, almost all of our other corporate actors had markedly different approaches and styles to innovation, having synergies in some attributes of their style but discrepancies in others. The Algal Carbon Conversion Flagship, being an industry consortium backed with public funds, shared no discernable attributes with the more tightly controlled Aurora Algae. Statoil and DONG Energy, by contrast, shared their approach to inclusivity and were also closer together in terms of less stringent control of information and decentralization. Tesla and the Volkswagen Group had the same style towards cooperation and similar attributes related to holism and focusing on social dimensions, but differed in all other respects.

In addition, and perhaps unsurprisingly, the corporate research approaches involving algal biofuel, CCS, and EVs were not transferrable to each other or to offshore wind energy. Innovation approaches are not only technology specific, but firm, location, and (likely) time specific. The potential for different permutations leads to an almost endless number of possible stylistic combinations. This suggests there although every firm has its own approach, none are universal—meaning, perhaps as expected, that each manages the “paradox of openness” in its own way. This serves as a critique to overly deterministic or linear notions of innovator, research and development that attempt to reduce it to a series of steps or variables easy to predict or model.

Furthermore, in each of our four areas—algal biofuel, CCS, EVs, and offshore wind—the innovation profiles depicted reveal elements of conflict and competition among both various stakeholders as well as levels of technological readiness—suggesting an invariable downside to openness and inclusion. Our algal biofuel case study exhibited conflict between agriculture promoters and

environmentalists concerned about pathogens and future contamination, essentially pitting industrial concerns against environmental ones. Our CCS case study revealed a conflict over whether the technology should be open and accessible to all, so experiments can proceed in a transparent manner, or hoarded and protected for its intellectual property. Our EV case study sees conflict over different visions as to whether our future automobiles should be fully electric, or a mix of electric and internal combustion (hybrids) or using advanced fossil fuels (such as hyper-efficient diesel). Our offshore wind case study reveals conflicts about in-house versus outsourced research and who ought to control private research.

Moreover, as established in the management literature we sampled, the strategic choices of corporate firms lead to differences and similarities, yet the choices are also conditioned by their resources and capabilities. Across technologies, the lifecycle stage of the technology seems to have an impact on the firms' openness versus closeness choices. Nascent technologies appear to benefit from openness and involvement of different stakeholders whereas new technologies with commercialization potential may experience more closeness. Algal fuel technologies versus EVs affirm this point. Further, firms may be more open versus closed in different sections of the value chain of the new technology product. For example, the value creation end of the value chain may experience more openness whereas the value capture end may experience more closeness. These themes do imply that future work needs to focus less on informing “what” is happening with clean technology innovation and development to “why” it is happening. The implication is that corporate innovation in the energy sector remains as ripe for further inquiry as it is growingly important in helping society achieve its low-carbon goals.

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